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CALCULATION OF THE EFFECT OF A SUPPORTING STRUT AND THE FREE SU--ETC(U)
APR 79   C W DAWSON

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Potential flow calcuations were made to determine the effects of a supporting strut and the free surface on the drag on a test model of a torpedo. These calculations show that the strut and free surface had significant effects on the test measurements. These calculations also show that the XYZ Free Surface Program can provide useful results for Froude numbers up to but not much larger than 1.5.

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## ABSTRACT

Potential flow calculations were made to determine the effects of a supporting strut and the free surface on the drag on a test model of a torpedo. These calculations show that the strut and free surface had significant effects on the test measurements. These calculations also show that the XYZ Free Surface Program can provide useful results for Froude numbers up to but not much larger than 1.5.

## ADMINISTRATIVE INFORMATION

## INTRODUCTION

When a model is tested in a towing tank, there is always the question of the effect of the test equipment on the results. The test considered here is that of a model torpedo towed beneath the water surface in a towing tank. The model is supported by a sting and strut attached to the towing carriage above (see Figure 1). The calculations reported here were made to obtain values for the effects of the strut and free surface on the drag measurements for the torpedo model.

All calculations were made with the XYZ Free Surface Program[1]* (XYZFS). This program was designed to handle problems for ships moving at Froude numbers between 0.2 and 0.6. This problem has the largest Froude numbers (1.5 to 3.0) yet attempted with the XYZFS program and thus is a good problem to test the program's limitations. The results clearly demonstrate the limitations as well as the usefulness of the program.

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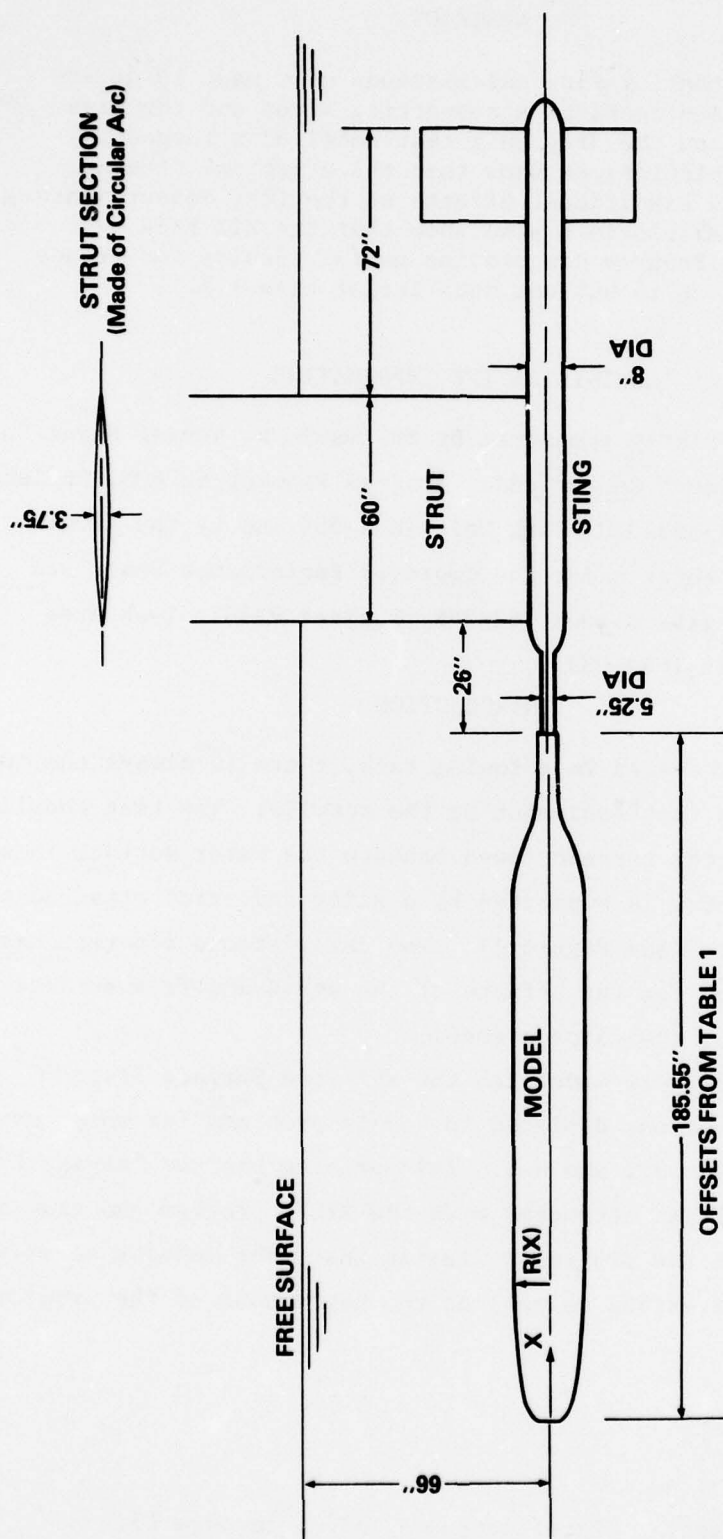* A complete listing of references is given on page 13.

Figure 1 - Model and Supporting Sting and Strut

## XYZ FREE SURFACE PROGRAM

The XYZ Free Surface Program (XYZFS), which was used for these
calculations, computes the steady state motion of fluid past a body in or
near a free surface.  Part of the solution process involves solving the
double model problem (i.e., the body and its image above a plane of
symmetry).  When only a double model solution is desired, the program may
be stopped at this stage.

The method used is a modification of the source-sink boundary
integral method originally developed by Hess and Smith[2] and used in the
XYZ Potential Flow Program.[3]  The velocity field is written in terms of
integrals of a source density over the body surface, the image of the
body above the free surface, and a limited region of the undisturbed
free surface.  The surfaces are approximated by a set of plane quadri-
lateral panels and the source density is approximated by a constant in
each panel so that the integrals are replaced by a sum over the panels.

The free surface condition is linearized in terms of the double model
solution and is applied at the undisturbed free surface.  The resulting
partial differential equation can be written in terms of derivatives
taken along streamlines of the double model solution.  These derivatives
are approximated by a one-sided, special four-point, upstream, finite
difference operator applied to the velocity at the centers of the panels.
The use of upstream differences prevents waves from developing upstream
from the body and the special four-point operator avoids large damping
errors.

The free surface equations and the equations for the body boundary
condition are solved simultaneously to obtain the source density.  Then
the velocity is computed from the source density and finally the
pressure, drag, and free surface elevation are computed from the velocity.

## GEOMETRY OF THE PROBLEM

The model torpedo is axisymmetric with a maximum diameter of 20.8
inches (52.8 cm) and a length of 185.55 inches (471.3 cm).  Values of X
(the distance from the nose along the axis of symmetry) and R (the local

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radius of the model) are given in Table 1. The geometry of the sting and strut is shown in Figure 1.

TABLE 1 - VALUES OF X AND R FOR THE 208-PANEL
REPRESENTATION OF THE MODEL

| Offset # | X inches | R inches | Offset # | X inches | R inches |
|----------|----------|----------|----------|----------|----------|
| 1 | 0.0 | 0.0 | 15 | 94.6000 | 10.4000 |
| 2 | 0.0 | 1.1746 | 16 | 114.6000 | 10.4000 |
| 3 | 0.1268 | 3.1662 | 17 | 128.6000 | 10.4000 |
| 4 | 1.1821 | 4.8146 | 18 | 138.6500 | 10.4000 |
| 5 | 3.0535 | 5.9519 | 19 | 146.0141 | 10.3303 |
| 6 | 4.9287 | 6.6516 | 20 | 150.3185 | 9.8106 |
| 7 | 8.8807 | 7.6239 | 21 | 155.5384 | 8.3730 |
| 8 | 11.5272 | 8.0852 | 22 | 160.6131 | 6.4433 |
| 9 | 15.2695 | 8.5920 | 23 | 164.6801 | 4.9260 |
| 10 | 21.4791 | 9.1965 | 24 | 167.8000 | 3.9929 |
| 11 | 28.8355 | 9.6755 | 25 | 173.1417 | 3.1194 |
| 12 | 41.8463 | 10.1512 | 26 | 179.6500 | 3.0000 |
| 13 | 54.8647 | 10.3480 | 27 | 185.5500 | 3.0000 |
| 14 | 73.6000 | 10.4000 | | | |

A number of changes were made in modeling the sting to simplify the calculations. The last part of the sting including the stabilizing fin was omitted and the trailing end of the sting was left open. Fluid thus passes out the open end of the sting so that, in effect, the sting extends to infinity. Also the sudden change in diameter from 6 inches (15.24 cm) to 5.25 inches (13.33 cm) where the sting attaches to the model was changed so that the sting tapers from 6 inches (15.24 cm) to 5.25 inches (13.33 cm) over a length of 8.45 inches (21.46 cm).

Four different configurations were used in the calculations. In case 1 the model without the sting and strut is in an infinite fluid. In case 2 the model is placed below a plane of symmetry which roughly approximates the free surface. In case 3 the model is below the plane of

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symmetry and the sting and strut are included. In case 4 the model without the sting and strut is below a free surface. In cases 1, 2, and 4 the end of the model, where the sting would be attached, is left open. Fluid passes out the open end giving the effect of an infinite sting. Thus in all cases the model is in effect attached to an infinite sting.

## PANELING

The number of panels that can be used with XYZFS is limited to 568 by the computer memory size, and the computer time required increases as the square of the number of panels. For these reasons the model, sting, strut, and free surface are rather crudely approximated in the calculations and it is necessary to determine to what extent the results are sensitive to the paneling arrangement.

The model was approximated by arrangements of 128, 208, and 416 panels. Because the problem has left-right symmetry, only one side is represented by the panels. (In case 1 only 1/4 of the model need be represented so only half of the stated number of panels was actually used.) The panels for the model were arranged with 8 panels from bottom to top (22.5 deg intervals) and 16, 26, or 52 panels in the X-direction.

Two paneling arrangements for the sting and strut were used. The first used 144 panels and the second 204 panels. The paneling arrangement with 208 panels for the model and 204 panels for the sting and strut is shown in Figure 2.

Calculations with the free surface were made for speeds of 20 and 30 knots. Originally calculations were to be made for a speed of 40 knots, but problems encountered at 30 knots indicated that calculations at 40 knots would be useless.

For a model speed of 20 knots, calculations were made with six different representations of the free surface. In the first representation the region of the free surface represented by panels extended 790 inches (2007 cm) forward, 905 inches (2299 cm) behind, and 520 inches (1321 cm) to the side of the center of the model. This region was represented by a 38 by 8 array of panels. The panels varied in size being smallest near the model where they were 30 inches (76.2 cm) by
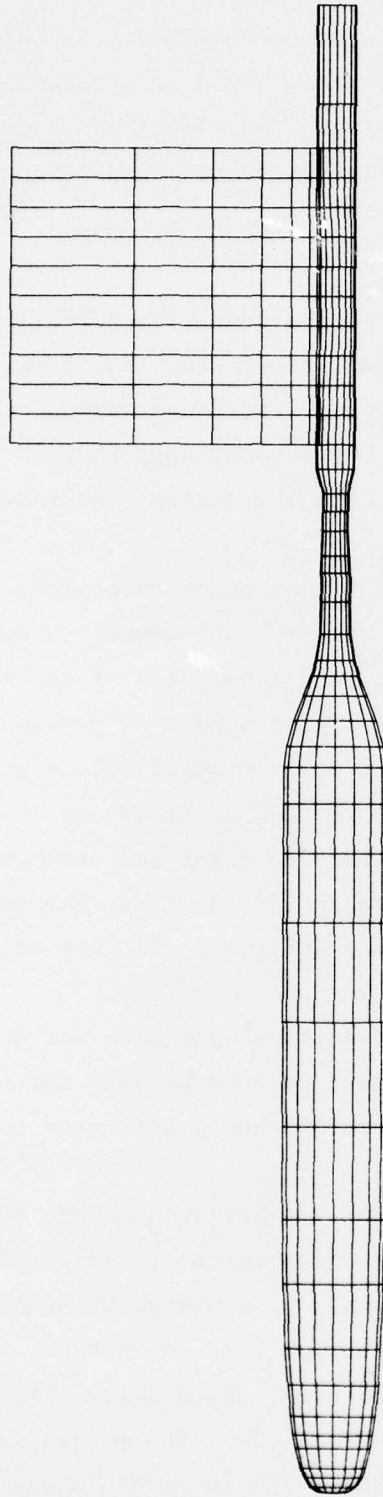
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Figure 2 - Panel Arrangement with 208 Panels on the Model and
204 Panels on the Sting and Strut

30 inches. The other representations were similar to the first but the panel arrangements were changed in a systematic way to test the effects of the changes. The other representations used are as follows:

1. A long region with a 48 by 8 array of panels extending 1270 inches (3226 cm) forward and 1390 inches (3531 cm) behind the center of the model.

2. A wider region with a 38 by 10 array of panels extending 620 inches (1574 cm) to the side.

3. The basic region with smaller panels. A 44 by 10 array of panels was used with the panels nearest the model being 25 inches (63.5 cm) by 25 inches. This array of panels is shown in Figure 3.

4. The basic region with larger panels. A 22 by 6 array of panels was used with the panels nearest the model being 50 inches (127 cm) by 50 inches.

5. A short region with a 30 by 8 array of panels extending 540 inches (1372 cm) forward and 710 inches (1803 cm) behind the center of the model.

For a model speed of 30 knots, calculations were made with the different representations of the free surface. The first representation was the same as the first representation for 20 knots. The second representation was longer and wider with a 44 by 10 array of panels extending 1740 inches (4420 cm) forward, 1810 inches (4597 cm) behind, and 1000 inches (2540 cm) to the side. The panels near the model were the same size as for the first representation.

The 128-panel representation of the model was used for all free surface calculations.

## RESULTS

The drag coefficient $C_d$ is defined by the following equation:

$$C_d = \frac{1}{\frac{1}{2}\rho V_\infty^2 \nabla^{2/3}} \int \int \frac{1}{2}\rho (V_\infty^2 - V^2)N_x \, dA$$

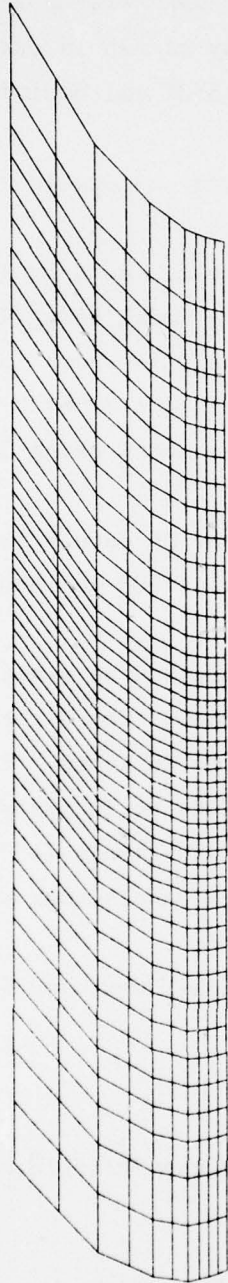where $N_x$ is the x-component of the unit normal vector to the model surface

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Figure 3 – A Computer Plot of the Model and the Panels
Representing the Free Surface

(Note: The model and panels are viewed from below
and to one side. The panels are on the flat,
undisturbed free surface. The panels toward the
side away from the model are increasingly angled
downstream.)

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V   is the fluid velocity on the model surface

$V_\infty$  is the fluid velocity at infinity

$\nabla$   is the volume of the model

$\rho$   is the fluid density

The integration is performed over the surface of the model except for a small hole where the sting attaches.

Normally $C_d$ is zero for potential flow about a body in an infinite fluid.  However, since there is a hole where the sting attaches, $C_d$ should have some small but nonzero value.  The actual value of $C_d$ is not important since it is the change in $C_d$ produced by the strut or free surface that is wanted.  The values of $C_d$ for the model with and without the strut are given in Table 2.  The changes in $C_d$ produced by the free surface are given in Table 3.

TABLE 2 - RESULTS OF DRAG CALCULATIONS WITH
AND WITHOUT THE STRUT

| No. of Panels on Model | | 128 | 208 | 416 |
|---|---|---|---|---|
| $C_d$ for Model in Infinite Fluid | | .004634 | .001860 | .000920 |
| $C_d$ for Model with Plane of Symmetry | | .004638 | .001861 | |
| Model with 144 Panels on Sting and Strut | $C_d$ | .003599 | .000816 | |
| | Change in $C_d$ | .001039 | .001045 | |
| Model with 204 Panels on Sting and Strut | $C_d$ | | .000813 | |
| | Change in $C_d$ | | .001048 | |

The value of $C_d$ is quite sensitive to the paneling arrangement on the model.  However, the effect of the strut on $C_d$ is insensitive to the paneling arrangement.  The change in the value of $C_d$ caused by the strut is so  insensitive that no additional calculations with the strut were considered necessary.

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TABLE 3 - RESULTS OF DRAG CALCULATIONS WITH
A FREE SURFACE FOR 20 KNOTS

| Free Surface Representation | Change in $C_d$ from Double Model Solution |
|---|---|
| Base Region   38 by 8 | .00025 |
| Long Region   48 by 8 | .00027 |
| Wide Region   38 by 10 | .00026 |
| Smaller Panels   44 by 10 | .00024 |

The calculations with the free surface were reasonably successful for a speed of 20 knots.  However, the number of panels available was barely adequate.  Both of the calculations made with the smaller region and the larger panels resulted in unreasonable solutions.  The solution for the larger panels had large oscillations in the free surface elevation between neighboring points.  The solution with the short region had a depression in the free surface ahead of the model.  The other calculations gave solutions that appear reasonable and the changes in $C_d$ are shown in Table 3.

The results of the calculations for a speed of 30 knots are more questionable.  The solution obtained with the basic region used for the 20-knot problem had a depression in the free surface ahead of the model and did not appear reasonable.  The larger and wider region gave a solution that appeared reasonable and gave a change in $C_d$ from the double model solution of .00004.  This value is not much larger than the size of the errors expected on the basis of the calculations at 20 knots.  Since the change in $C_d$ is so small and the accuracy obtained with the maximum number of panels is questionable, no additional calculations were made for 30 knots and plans for calculations for 40 knots were dropped.

## CONCLUSIONS

These calculations have shown that:

1. the supporting strut reduces the drag coefficient by .00104;

2. for a speed of 20 knots the free surface increases the drag coefficient by .00025;

3. the XYZ Free Surface Program can provide useful results for this type of problem for Froude numbers up to 1.5; and

4. for Froude numbers much larger than 1.5, it is not possible to provide adequate resolution near the model and at the same time cover a large enough part of the free surface to obtain results accurate enough to be useful.

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